Sensor Data Fusion for Smart Global and Local Structural Health Monitoring

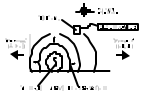
PHYSICAL ACOUSTICS CORPORATION
A MISTRAS Holdings Company

SARNOFF Corporation

ACTIVE/PASSIVE ACOUSTIC CONCEPT

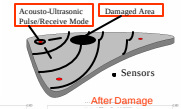
PASSIVE:
AE AND VIBRATION

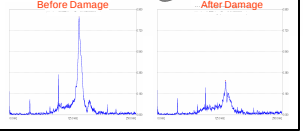
- Acoustic Emission and Vibration sensors placed on a structure
- Detection of an acoustic wave generated in a structure
- Sensors detect fatigue, vibration, damage etc.



ACTIVE:
ACOUSTO-ULTRASONIC

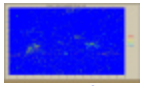
- Acoustic Emission sensors in the pulse and receive mode (AU)
- Signal over a damaged area is different than undamaged area



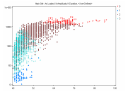


Source Location - Arbitrary Sensor Placement

- Sensors placed anywhere within rectangular coordinate system
- Used for planar location
- Algorithm is overdetermined



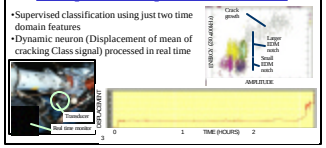
Pattern Recognition Used to Classify Sources



- NOESIS software provides advanced data analysis, pattern recognition and neural networks
- LVQ (Kohonen variant) unsupervised neural network
- Used to classify AE signals from thermal and electrical faults

Example of Helicopter Health Monitor

- Supervised classification using just two time domain features
- Dynamic neuron (Displacement of mean of cracking Class signal) processed in real time

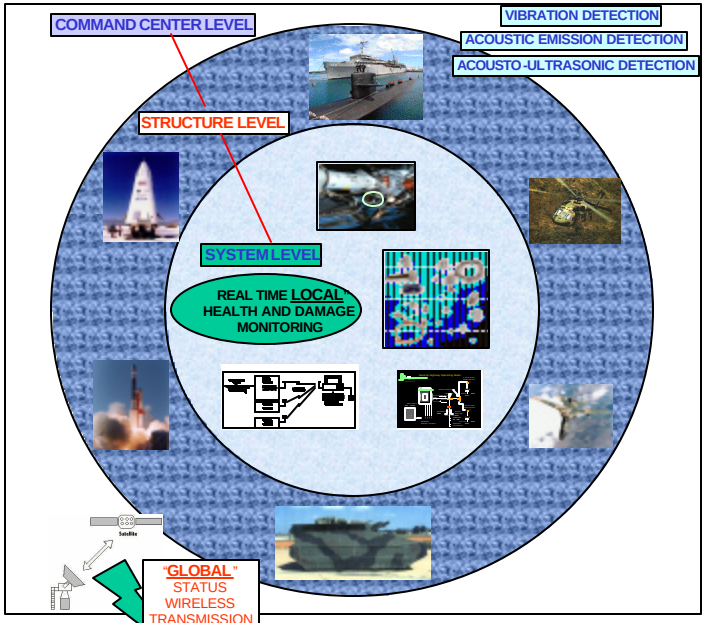


PHYSICAL ACOUSTICS CORPORATION
Vibra-Metrics
QSI Quality Services Laboratories, Inc.
NDT Automation

In 1978, **PAC** was founded by Bell Telephone Laboratories scientist, Dr. Sotirios J. Vahaviolos in the University town of Princeton, New Jersey, USA. Since its founding, **PAC** has grown to become the acknowledged world leader in the physical acoustics field.
Our "Group" develops and manufactures all our test equipment and sensors under ISO 9001 quality standards. We employ leading-edge technologies for nondestructive testing and predictive maintenance, such as advanced acoustic emission, acousto-ultrasonics, ultrasonics, eddy current, radiography, vibration monitoring and resistivity systems. In addition, we provide on-line asset management by employing Internet-based data acquisition and real-time assessment of the world's industrial & public infrastructure.

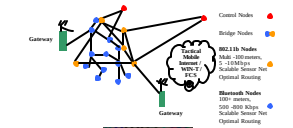
SARNOFF Corporation

The Sarnoff Corporation was established in 1942 as the RCA research laboratories and became a subsidiary of SRI International in 1987. It is located on a 360 acre campus in Princeton, NJ and employs a technical workforce of over 300 engineers and scientists.
Sarnoff's primary business is the development of advanced technologies for the government and new products for corporate customers in the areas of Information Processing, Semiconductors, and Biotechnology. It maintains contracts with over 40 government agencies and has created 20 technology venture companies over the past decade. Sarnoff has in-house manufacturing capabilities, through its wholly owned subsidiary HiTec, that includes IC design and fabrication, advanced materials and displays, and opto-electronics.

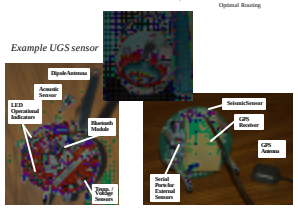


Ad-Hoc Networks

The first ad-hoc network designed specifically for sensors



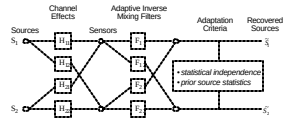
Example UGS sensor



- Developed for the Air Force, expanded under DARPA SUOSAS, adapted to ARMY unattended ground sensors (UGS)
- Self-organizing, self-healing network using commercial components
- Innovative routing without initial flooding or periodic routingupdates
- Automated routing and relay capability at every network node
- No housekeeping traffic - long battery life
- Support for multiple link types (e.g. Ethernet, 802.11b, Bluetooth)

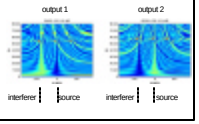
Blind Source Separation and Deconvolution

Recovers passive sources from an array of sensors

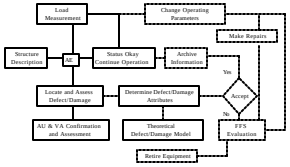


example application: voice control of TV

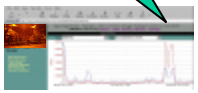
sample blind beam patterns



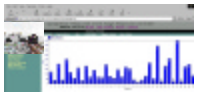
DAMAGE DETECTION FLOW CHART



- Sensor Fusion - One device can give you AE, AU and VA while other devices measure stimulus
- Initial defect/damage detection can be by any one method with the other methods verifying
- Defect/damage characterization uses all methods - either direct or through deconvolution
- Damage model determines Fitness-For-Service - this input is expected from expert in Academia



Activity versus Time Graphs

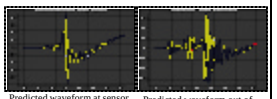


Channel Activity graph

Report Page

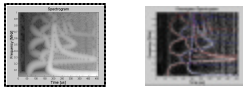
"INTERNET GLOBAL MONITORING VIA SATELLITE OR LOCALLY VIA MODEM"

AE WAVEFORM PREDICTION FOR CRACK SOURCE AND DECONVOLUTION



Predicted waveform at sensor face — Predicted waveform out of sensor

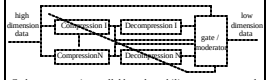
Using PLOTRLQ software from PAC



Spectrograms can be generated using short time FFT or wavelet transform and enhanced for comparison with theoretical dispersion curves. The ratio of the amplitude of mode pairs can be used to reconstruct the source function.

Data Fusion

Optimal dimensionality reduction based on competition between adaptive CODECS

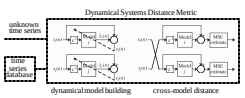


- Codecs compete in parallel based on ability to compress and decompress data with least distortion.
- System automatically learns to segment data stream based on best local representation.

• Fancourt C. and Principe J., Competitive principal component analysis for locally stationary time series, *IEEE Trans. on Signal Processing*, 1998.

Time Series Classification

Based on distance between dynamical systems



- Based on information-theoretic distance between time series.
- Applicable to deterministic, stochastic, and chaotic time series.

• Craig Fancourt and Jose Principe, "Modeling, Segmentation, and Classification of Nonlinear Nonstationary Time Series", *in Nonlinear Dynamical Systems* (Haykin ed.), Wiley, New York, 2001.

Acoustic Signal Processing

Sarnoff algorithms for separating signals from noise

- **Single channel noise reduction**: removes noise from a single audio channel without prior knowledge of the noise or when it occurs (patented).
- **Adaptive noise cancellation**: filters and subtracts noise from an audio channel when an isolated reference measurement of the noise is available.
- **Adaptive beamforming**: array processing algorithm that exploits knowledge of the array geometry and source geometry relative to the array.
- **Blind source separation**: blind array processing algorithm that exploits the statistical independence of the sources (patented).
- **Geometric source separation**: array processing algorithm that combines adaptive beamforming and blind source separation by exploiting all available knowledge about the acoustic scene: array geometry, source geometry, and statistical independence of the sources (patented).

- Developed and refined over 10 years of R&D for government and industry.
- Frequency domain algorithms operate in in real time on currently available processors.
- 4 patents, 3 book chapters, dozen journal and conference publications.